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Research Article

Conserving embodied energy using hollow clay blocks for walls and roofs-case studies of 20 houses in Bengaluru, India

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ABSTRACT

A substantial amount of energy is spent in the manufacturing processes and transportation of various building materials. Conservation of energy becomes very important in the context of limiting greenhouse gas emission into the atmosphere. Selection of materials and technologies, in building construction, should not only satisfy the felt needs of the users and the development needs of the society but also minimize the adverse impact on the environment. This paper documents, on a comparative basis, the savings in embodied energy of walling and roofing systems using hollow clay blocks. It analyses and highlights the savings in the embodied energy in relation to conventional walling and roofing in residential designs, in the Indian urban context. Case studies of 20 projects which were designed and executed by the first author from 1989 to 2006 have been examined. This research was done at the RV College of Architecture, Bengaluru, between 2008 and 2014, when both the authors were serving the institution.

Keywords: Conserving, embodied energy, hollow clay blocks, Indian context, walls and roofs

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INTRODUCTION

Modern construction employs significant amounts of energy, including thermal energy and energy for transport of building materials. Energy reduction in building construction can be achieved in several ways which include: (a) Maximizing the participation of the stakeholders in construction industry, (b) judicious utilization of available energy, (c) optimal use of resources such as materials, machinery, and money (d) evolving innovative designs, (e) adopting appropriate technology, (f) avoiding/minimizing time and cost overrun and quality deficiencies, (g) efficient construction management to ensure best value for clients' money, and (f) minimizing wastages. All these measures will have a critical role to play in the process of managing embodied energy efficiently.[1] Figure 1 shows the share of built environment in energy consumption and carbon emission. Worldwide, the built environment is currently responsible for 25–40% of energy use, 30–40% of solid waste generation, and 30–40% of global greenhouse gas emissions.[2] The energy consumption in built environment may be categorized as follows: [3]

a. Embodied energy in building materials
b. Energy consumption during building construction
c. Energy utilized for maintenance during the life span of a building and
d. Energy spent in the demolition of the building at the end of its life.

The above four categories together constitute "life cycle" energy cost of a building. Category (c) refers to the energy spent to maintain and meet the needs of the occupants of a building. This, many a time, is electrical energy used in lighting, air conditioning, water pumping, operation of elevators, and usage of domestic electronics such as computers, television sets, refrigerators, ovens, heaters, washing machines and fresh air, and exhaust fans. Categories (a) and (b) together constitute "embodied energy" in a building. Building systems need to be examined for their embodied energy consumption.

Figure 2 shows a comparison between conventional and alternative construction in terms of savings in total embodied

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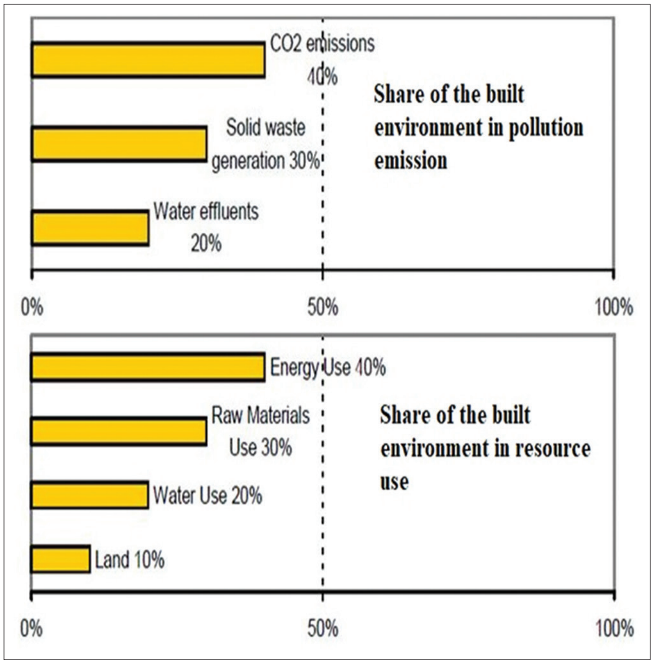

Figure 1: Share of the built environment in pollution emission and resource use (unep/dtie, 2006)

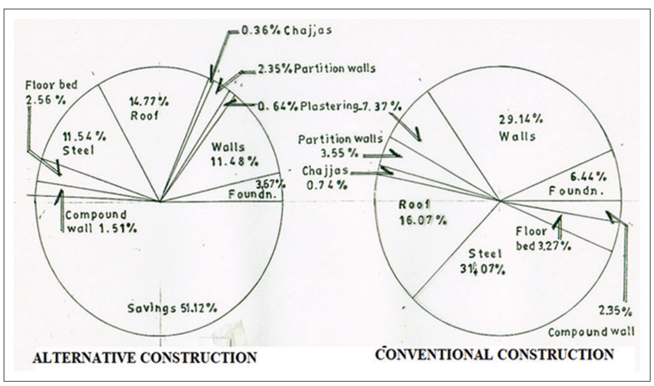

Figure 2: Comparison between conventional and alternative construction

energy.[4] It also shows the percentage share of different components of structure with respect to embodied energy consumption. The percentage component of embodied energy in conventional construction for foundations, walls, plastering, partition walls, chajjas/sunshades, roof, steel, floor, and compound walls is 6.44, 29.14, 7.37, 3.55, 0.74, 16.07, 31.07, 3.27, and 2.35%, respectively. The percentage component of embodied energy in alternative construction for the corresponding items mentioned is 3.67, 11.48, 0.64, 2.35, 0.36, 14.77, 11.54, 2.56, and 1.51%, respectively. The savings in the total embodied energy in alternative construction are 51.12% of that in conventional construction.

Embodied energy in walls and roofs constitutes 45.21% in conventional construction. Steel accounts for 31.07%

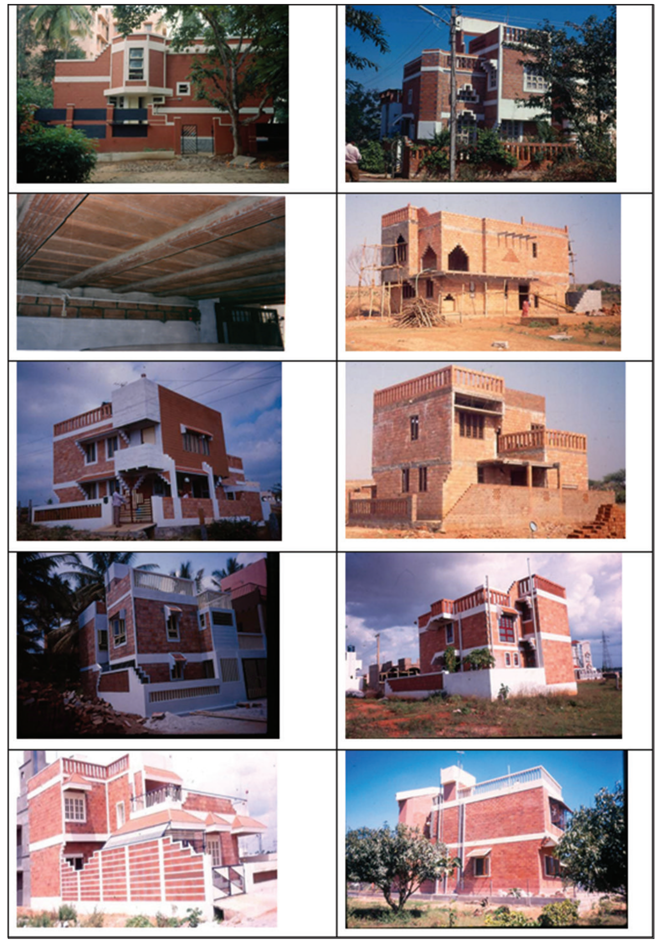

Figure 3: Views of cases 1–10

of embodied energy. The focus of alternative building systems is on reduction and savings in the components of the structure. From over 50 houses identified, 20 were selected for the purpose of case studies. These residential projects were executed using different combinations of hollow clay blocks for walls and roofs, having a built-up area ranging from 1410 to 4020 sq ft (131.04–373.61 sq.m). The house owners belonged to the middle-income group of the population, who wanted to save costs, as a primary requirement. They also had the zeal to own unconventional houses for themselves. All these 20 projects of the case studies have been designed and executed by the first author from 1989 to 2006.

The individual quantities of wall types and roof types used in the respective case studies are estimated. Considering the embodied energy values of materials involved in the respective wall and roof types, the embodied energy per unit of wall and roof is calculated.[5] Further, using the embodied energy values per unit of these wall and roof types, the total amount of embodied energy in each of the case studies is computed. Conclusions are then drawn based on the total values of

Table 1: List of case studies

Name and address	Started	Completed	Area in S ft	Area in S mt	Cost in Indian rupee	Wall type	Roof type
H.V. Srinivas, 95/1, 6th main, Malleshwaram, Bengaluru	November-89	February-91	1410	131.04	260,000 183/Sft	W1	R1
D. Sundar 371 ideal homes colony, Bengaluru	March-94	January-95	1780	165.43	457,000 256/Sft	W2	R2
Tameenidhi Saijee Rao 245, BCC lay out, Bengaluru	November-95	June-96	1520	141.26	576,000 379/Sft	W2	R3
K. N. Narendra 21 gidada Konena Halli, 4 Bengaluru North	July-96	August-97	1690	157.06	684,000 405/Sft	W2	R4
Arun Marathe 226 sideda halli, hesarghatta Road, Bengaluru	August-96	May-97	1480	137 55	614,000 415/Sft	W2	R4
S. Ganesan 52 gidada konena halli, Bengaluru North	August-96	June-97	1410	131.04	590,000 418/Sft	W2	R4
R.D. Philip A-09 coconut garden nagarabhavi Bengaluru	July-97	January-98	1410	131.04	600,000 425/Sft	W3	R4
Upendra M Chiplunkar 30 bagala kunte hesarghatta road Bengaluru North	August-97	April-98	1440	133.83	620,000 403/Sft	W3	R4 and R5
N. M.Vishnu 1095 H.S.R lay out Bengaluru	November-98	July-99	2310	214.68	114,5000 495/Sft	W3	R4
A. B.Ganapathy 34 Ferns meadows hennur Road, Bengaluru	April-99	December-99	3120	289.96	1,280,000	W4	R4
H. I. Somashekhar, Govindarajanagar, Bengaluru -40	March-01	December-01	1662	154.46	730,000 440/Sft	W2	R6 to R9
P. Udayashankara 889 3rd cross I main V stage BEML lay out Bengaluru	November-01	May-02	2170	201.67	1,010,000 465/Sft	W2	R7, 10 and 11
Nagabhushan G, H.M.T lay out tumkur road Bengaluru	March-03	December-03	2610	242.57	1,300,000 498/Sft	W5	R7, R9 and R12
Sahana and Keshav Prasad 14 Kumaraswamy layout Bengaluru	November-03	May-04	2160	200.74	1,200,000 556/Sft	W2	R14
Balakrishna Kakathkar N.G.E.F lay out Nagarabhavi Bengaluru	December-03	Sepetamber-04	4020	373.61	2,370,000 590/Sft	W2	R9 and R13
C. R. Arjun Royal County Jambu savari Dinne Bengaluru	January-04	March-05	2640	245.35	146,500 535/Sft	W2	R12 and R13
M. Rajendra Samrat lay out Bengaluru	February-04	January-05	1760	163.57	932,000 530/Sft	W2	R7, 9, 12 and 13
Ravishankar Konanakunte Bengaluru 18 South	July-04	April-05	2230	207.25	1,242,000 540/Sft	W2	R9 and R13
Mahabala bhat upkar residency ullal Bengaluru	February-05	June-06	2100	195.17	1,218,000 580/Sft	W2	R14 and R15
S. Nagaraj bannerghatta road Bengaluru	March-05	October-06	2020	187.73	1,131,200 560/Sft	W2	R9 and R11

embodied energy saved in each of the cases as compared to conventional options.[6]

Table 1 shows the list of cases studied, names of the owners, address, period of construction, cost in Indian rupee, built

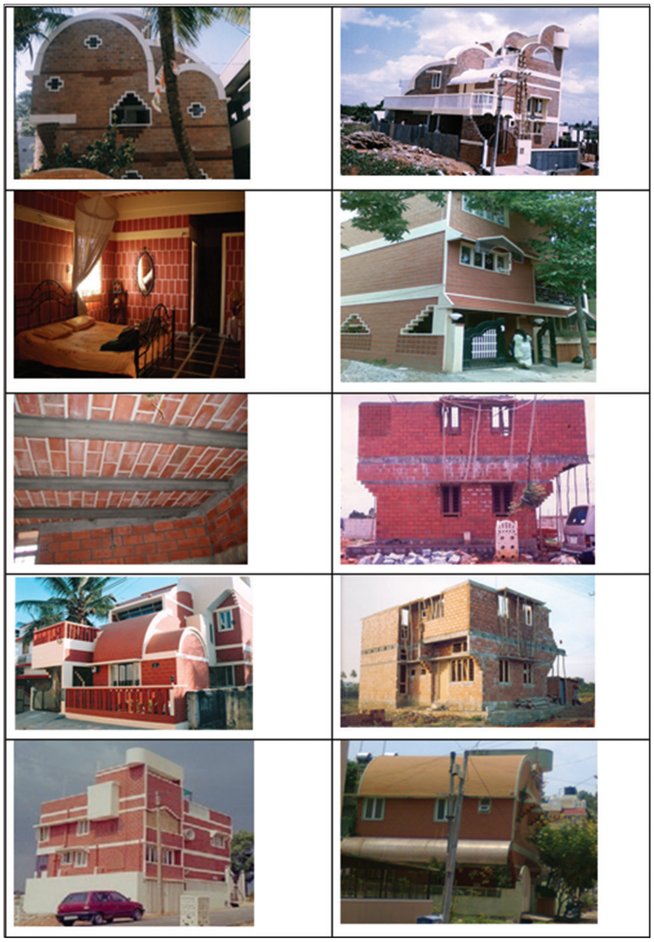

Figure 4: Views of cases 11–20

area in sq. ft (and in sq.m), cost per sq ft of construction, wall types, and roof types used in the cases. Figures 3 and 4 show the illustrations of cases 1–10 and of cases 11–20, respectively.

WALL TYPES

Figure 5 shows the details of wall types W1–W6. Wall type W1, for 6” thick wall, is built using 12” × 6” × 6” perforated clay blocks (hollows vertical and perpendicular to ground) with 1/2” thick 1: 1:6 soil-cement mortar containing 1 unit of cement, 1 of sieved soil, and 6 of stone dust (quarry dust). Care is taken to stop the mortar falling into the cavities, by keeping a wooden plank, over the central hollows during construction. Wall type W2, for 6” thick wall, is built using 12” × 6” × 6” hollow clay blocks (hollows horizontal and parallel to ground) with 1/2” thick 1: 1:6 soil-cement mortar containing 1 unit of cement, 1 of sieved soil, and 6 of stone dust. As the hollows are parallel to the ground, the chances of mortar falling into the cavities are eliminated. Wall type W3, for 6” thick wall, is built

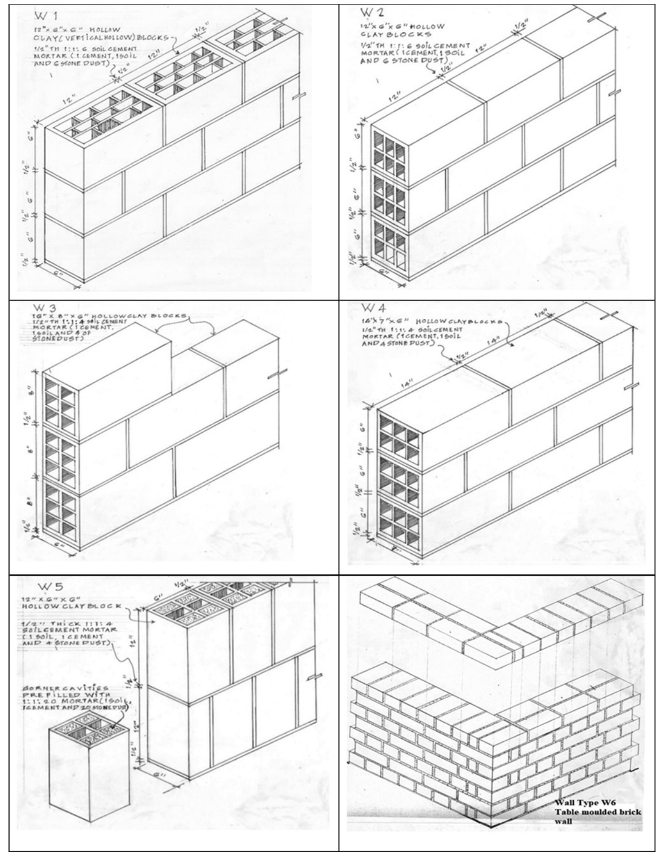

Figure 5: Wall types W1–W6

using 16” × 6” × 8” hollow clay blocks (hollows horizontal and parallel to ground) with 1/2” thick 1: 1:6 soil-cement mortar containing 1 unit of cement, 1 of sieved soil, and 6 of stone dust. Wall type W4, for 7” thick wall, is built using 14” × 6” × 7” hollow clay blocks (hollows horizontal and parallel to ground) with 1/2” thick 1:1:6 soil-cement mortar containing 1 unit of cement, 1 of sieved soil, and 6 of stone dust. Wall type W5, for 6” thick wall, is built using 12” × 6” × 6” hollow clay blocks (hollows perpendicular to ground) with 1/2” thick 1:1:6 soil-cement mortar containing 1 unit of cement, 1 of sieved soil, and 6 of stone dust. To prevent the mortar from falling into the cavities, the four corners of the hollow cavities of the blocks are filled with lean mortar and cured. The lean mortar used for filling the corner cavities of the blocks is 1:1:20 ratio (1 unit of cement, 1 of sieved soil, and 20 of stone dust). Wall type W6 is the conventional 9” (230 mm) thick table molded brick (TMB) wall in 1:6 cement mortar containing 1unit of cement and 6 of sand/fine aggregate.

ROOF TYPES

Figures 6-8 show the details of roof types R1–R3, R4–R6, and R7–R15, respectively. Roof type R1 is built using

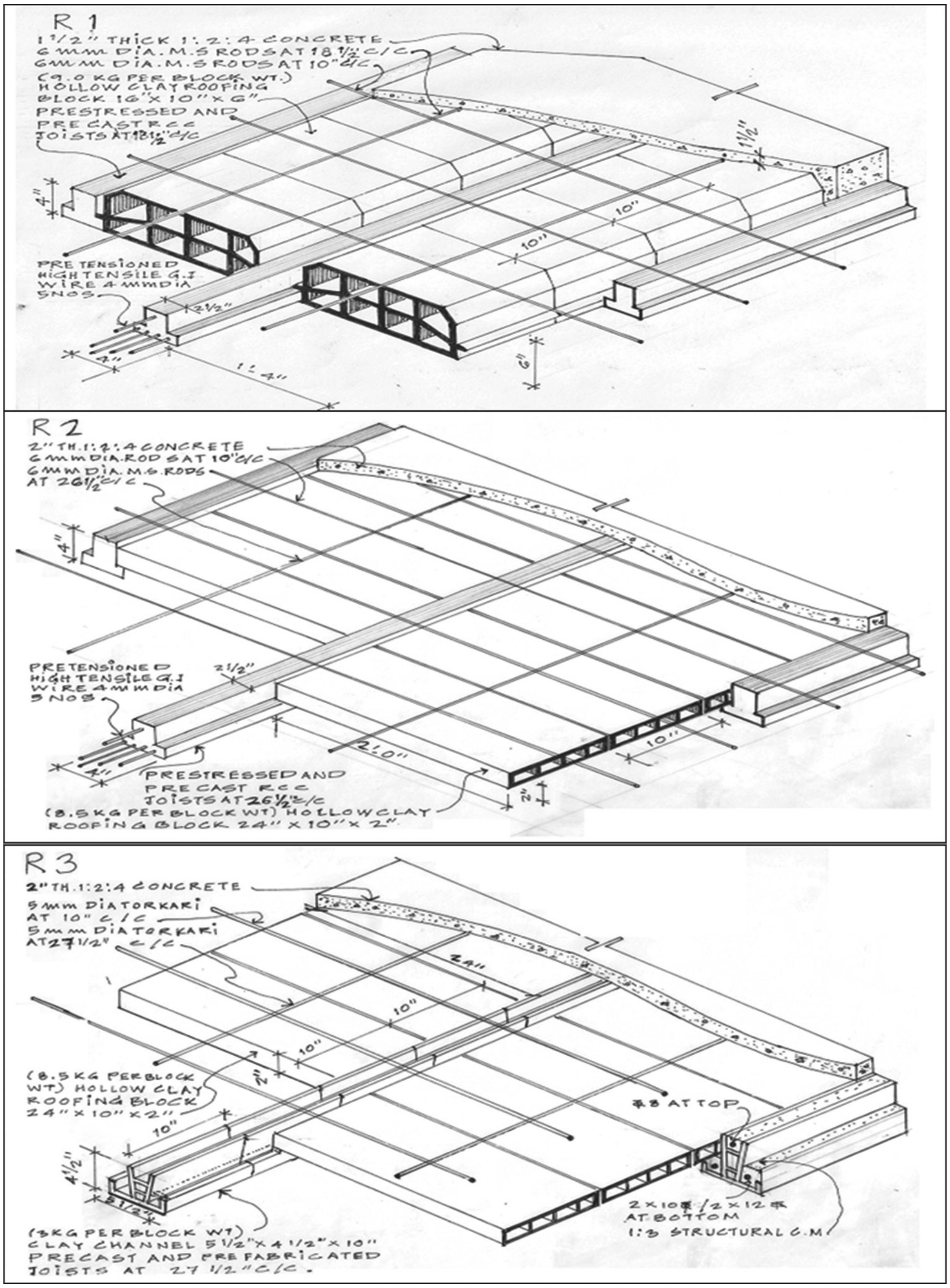

Figure 6: Roof types R1–R3

16” × 10” × 6” hollow clay roofing blocks over prestressed and precast RCC joists, with 1 1/2” screed concrete on top. Roof type R2 is built using 24” × 10” × 2” hollow clay roofing blocks over prestressed and precast RCC joists, with 2” screed concrete on top. Roof type R3 is built using 24” × 10” × 2” hollow clay roofing blocks over precast joists cast using 51/2” × 41/2” × 10” clay channels. 2” thick 1:2:4 RCC screed concrete is laid on top. The variation in spans of roof type R3 has generated roof types R3A and R3B, other factors remaining the same. Roof type R4 is built using 24” × 10” × 2” hollow clay roofing blocks over precast RCC joists. RCC joists are designed for different spans and slight variations in spans of roof type R4 (other factors remaining the same) have resulted in the roof types R4A, R4B, R4C, R4D, R4E, R4F, R4G, R4H, and R4J. 2” thick 1:2:4 RCC screed concrete is laid on top. Roof type R5 is built as filler slab, using 24” × 10” × 3” hollow clay roofing blocks. Roof type R6 is built using 24” × 2” sedimentary stone slabs (locally called “cuddappah” stone slabs) over precast RCC joists, with 2” thick 1:2:4 RCC screed concrete on top. Roof

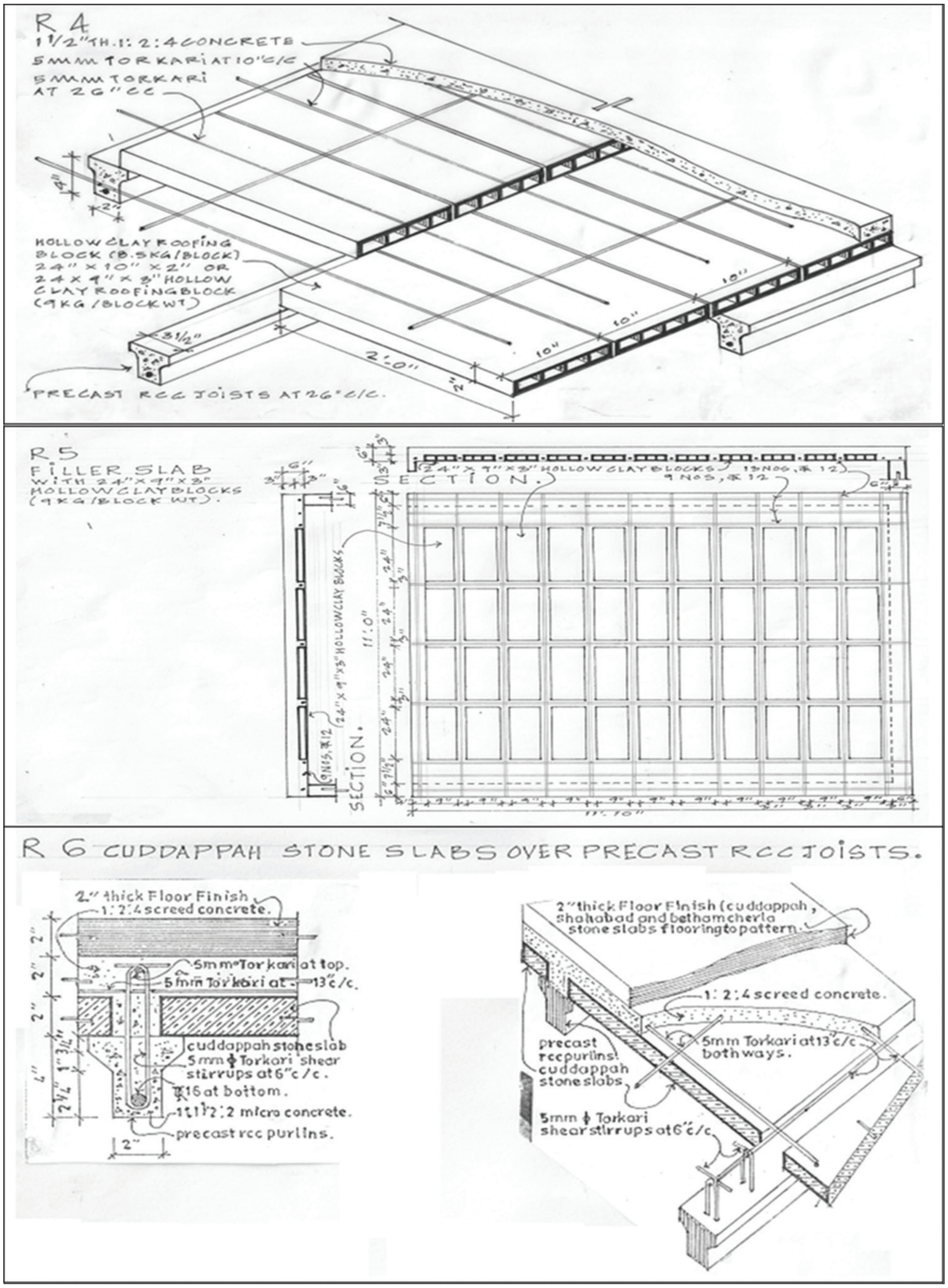

Figure 7: Roof types R4–R6

types R6A and R6B are caused by variations in spans of roof type R6 (other factors remaining the same). Roof type R7 is built using 84" × 13" × 3" precast hollow clay block panels (precast in 1:3 cement mortar using 12" × 6" × 3" hollow clay blocks) laid with 1:3 cement mortar over gabled (end walls to shape) walls, to form a vaulted roof.

Roof type R8 is built as a filler slab, using 12" × 6" × 4" hollow clay roofing blocks. Roof type R9 is built as vault, using 6" × 6" × 6" perforated clay blocks laid in 1:3 cement mortar and roof type 9A is also built as vault, using 12" × 6" × 6" hollow clay blocks laid in 1:3 cement mortar. Roof types R9A and R9B are vault forms caused by increase in spans (other factors remaining the same). Roof type R10 is built using 144" × 13" × 4" precast hollow clay block panels (precast in 1:3 cement mortar using 12" × 6" × 4" hollow clay blocks) laid with 1:3 cement mortar over gabled (end walls to shape) walls, to form a vaulted roof. Roof

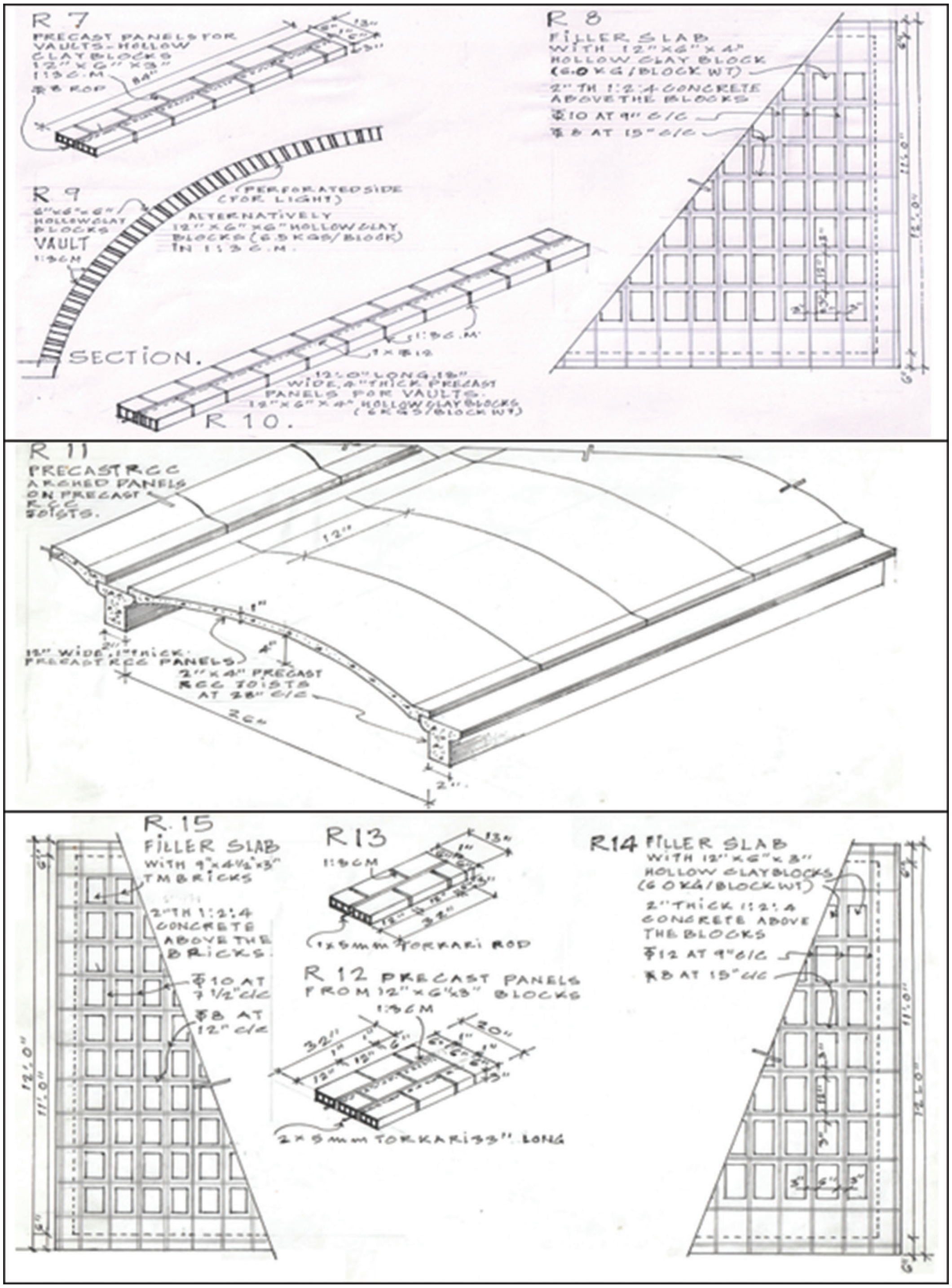

Figure 8: Roof types R7–R15

type R11 is built using 12” × 1” precast RCC arched panels over precast RCC joists, the valley between the panels filled with lean concrete and finished with 2” thick 1:2:4 RCC screed concrete on top. Roof Type R12 is built using 32” × 20” × 3” precast hollow clay block panels (precast in 1:3 cement mortar using 12” × 6” × 3” hollow clay blocks) over precast RCC joists, with 2” thick 1:2:4 RCC screed concrete on top. Roof type R13 is built using 32” × 13” × 3” precast hollow clay block panels (precast in 1:3 cement mortar using 12” × 6” × 3” hollow clay blocks) over precast RCC joists, with 2” thick 1:2:4 RCC screed concrete on top. Roof types R 13A, R13B, and R13C are caused by increase in spans of roof type R13 (other factors remaining the same). Roof type R14 is built as filler slab,

Table 2: Embodied energy in roof options

Roof type	Embodied energy in roof options in MJ
R1	334.67
R2	259.14
R3A	324
R3B	356.08
64A	302.67
R4B	370.67
R4C	385.28
R4D	422.26
R4E	447.12
R4F	398.26
R4G	413.79
R4H	440.97
R4J	515.84
R5	411.67
R6A	225.24
R6B	197.78
R7	225.96
R8	423.91
R9A	252.34
R9B	247.36W
R10	310.23
R11	356.84
R12	365.23
R13A	393.34
R13B	345.84
R13C	416.18
R14A	390.74
R14B	441.36
R15	415.99
RCC roof slab	730

using 12” × 6” × 3” hollow clay blocks. Roof types R14A and R14B are caused by increase in spans of roof type R14 (other factors remaining the same). Roof type R15 is built as filler slab, using 9” × 4 1/2” × 3” TMBs.

EMBODIED ENERGY IN THE 20 CASE STUDIES

Of the five wall options, W1–W5 used in the case studies, the embodied energy per sq. m of the wall is 259, 228, 200, 243, and 234 MJ/sq. m, respectively. W6, the conventional TMB walls that are used for load-bearing purposes contain 492.43 MJ/sq. m of embodied energy. Of the 29 different roofs (R1–R15) types, the embodied energy per sq. m of roof ranges from 197.78 to 447.12 MJ/sq. m, as shown in Table 2. Conventional RCC roof slab contains 730 MJ/sq.m of embodied energy. The total embodied energy contained in hollow concrete blocks (HCB) walls of all the 20 case studies, as shown in Table 3, is 927 GJ, whereas, comparatively if TMB walls were to have been provided, the total would have been 2018 GJ. The saving is 1091 GJ. There is further saving in external and internal wall plastering of the HCB walls used in the case studies. The total embodied energy contained in roofs of all the 20 case studies, as shown in Table 4, is 1144 GJ. Instead of these alternative roofs, comparatively, if conventional RCC roof slabs had been used, the total embodied energy would have been 2408 GJ. The saving is 1264 GJ. There is further saving in internal roof plastering. Savings in embodied energy thus achieved, are due to the technological options which also lead to sustainability. The total savings from the walls and roofs in the 20 case studies amount to 2355 GJ. The choice of materials used in the case studies was driven by local considerations. The alternative technology used was suitable for Bengaluru during the time framework mentioned. Along with technology, human effort and motivation were essential for achieving the goals of energy efficiency.[7]

Table 3: Embodied energy in hollow clay block walls

Case study	Wall type	Wall area in sq.m	Embodied energy (MJ) in sq.m Of wall	Total embodied energy (MJ) in wall	Total embodied energy GJ (MJ/1000) in wall
1	W1	197.83	258.97	51232	51
2	W2	242.3	227.52	55128	55
3	W2	154.95	227.52	35254	35
4	W2	195.9	227.52	44571	45
5	W2	171.72	227.52	39070	39
6	W2	200.03	227.52	45511	46
7	W3	164.55	199.71	32862	33
8	W3	206.04	199.71	41148	41
9	W3	231.84	199.71	46301	46
10	W4	206.87	242.57	50180	50

(*Contd...*)

Table 3: (*Continued*)

Case study	Wall type	Wall area in sq.m	Embodied energy (MJ) in sq.m Of wall	Total embodied energy (MJ) in wall	Total embodied energy GJ (MJ/1000) in wall
11	W2	170.45	227.52	38781	39
12	W2	157.74	227.52	35889	36
13	W5	250.2	233.84	58507	59
14	W2	163.48	227.52	37195	37
15	W2	218.27	227.52	49661	50
16	W2	242.15	227.52	55094	55
17	W2	214.9	227.52	48894	49
18	W2	252.28	227.52	57399	57
19	W2	265.44	227.52	60393	60
20	W2	191.79	227.52	43636	44

Table 4: Embodied energy in hollow clay block roofs

Case study	Roof type	Roof area in sq.m	Embodied energy MJ in sq.m of roof	Total embodied energy MJ in roof type	Total embodied energy in the case (rounded off with out decimals)	Total embodied energy in roof GJ (MJ/1000)
1	R1	120.43	334.67	40305.81	40306	40
2	R2	142.41	259.14	36902.83	36903	37
3	R3A	94.59	324.00	30647.16	48153	48
	R3B	49.16	356.08	17505.78		0
4	R4A	50.16	302.67	15181.93	51672	52
	R4B	28.98	370.67	10742.02		0
	R4C	66.83	385.28	25748.26		0
5	R4B	127.78	370.67	47364.21	47364	47
6	R4A	27.83	302.67	8424.21	43223	43
	R4B	93.88	370.67	34798.50		0
7	R4D	98.34	422.26	41525.05	49895	50
	R4E	18.72	447.12	8370.09		0
8	R4D	113.50	422.26	47926.51	53632	54
	R5	13.86	411.67	5705.75		0
9	R4F	180.48	398.26	71877.96	71878	72
10	R4F	84.68	398.26	33724.66	85993	86
	R4G	50.40	413.79	20855.02		0
	R4H	53.55	440.97	23613.94		0
	R4J	15.12	515.84	7799.50		0
11	R6A	16.74	225.24	3770.52	40175	40
	R6B	48.16	297.78	14340.31		0
	R7	25.55	225.96	5773.66		0
	R8	36.18	423.91	15337.06		0
	R9A	3.78	252.34	953.85		0
12	R7	2.72	225.96	614.61	50073	50
	R10	35.04	310.23	10870.15		0
	R11A	108.14	356.84	38588.68		0

(*Contd*...)

Table 4: (*Continued*)

Case study	Roof type	Roof area in sq.m	Embodied energy MJ in sq.m of roof	Total embodied energy MJ in roof type	Total embodied energy in the case (rounded off with out decimals)	Total embodied energy in roof GJ (MJ/1000)
13	R7	8.51	225.96	1922.92	75428	75
	R9A	27.98	252.34	7060.47		0
	R9B	40.73	247.36	10074.97		0
	R12	154.34	365.23	56369.23		0
14	R14A	67.45	390.74	26355.41	74022	74
	R14B	108.00	441.36	47666.88		0
15	R13A	182.34	393.34	71721.62	90849	91
	R9B	25.72	247.36	6362.10		0
	R14A	32.67	390.74	12765.48		0
16	R12	10.08	365.23	3681.52	72345	72
	R13A	174.56	393.34	68663.00		0
17	R7	13.77	225.96	3111.47	51400	51
	R9B	28.47	247.36	7042.34		0
	R12	32.40	365.23	11833.45		0
	R13A	8.78	393.34	3453.53		0
	R13B	75.06	345.84	25958.75		0
18	R9A	3.77	252.34	951.32	61096	61
	R13A	100.62	393.34	39577.87		0
	R13B	13.98	345.84	4834.84		0
	R13C	37.80	416.18	15731.60		0
19	R14B	161.89	441.36	71451.77	84930	85
	R15	32.40	415.99	13478.08		0
20	R9B	59.15	247.36	14631.34	83070	83
	R11A	191.79	356.84	68438.34		

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